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PROPOSAL FOR COMPLETION OF THE HR-73C CONFIGURATION

Engineering Report Number 5373

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ABSTRACT

The value of the HR-73C Configuration, the possibility of developing it, the technical problems involved, and the practicality of accomplishing the development are discussed. It is concluded that the "C" Configuration should and can be developed, and a proposed program to accomplish the development is presented.

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1 - INTRODUCTION

This proposal is made in response to the continued interest in the HR-73C Configuration. It is based on the performance which was observed and recorded during the test period in 1958. Although great strides were made in four years' development of the "C" System, the program was terminated just as this Corporation started to provide electromechanical engineering for the overall system.

At that time there were serious doubts that the configuration was capable of performance competitive to existing systems. As a result of the studies and modifications initiated by this corporation, field tests proved that the inherent performance of the "C" System is superior to any existing system of comparable weight and focal length. The limitations found in the "C" System during these tests were caused by unreliabilities of a mechanical and electrical nature.

The "C" System's unique capability of high oblique photography, and four advanced design features - (1.) A reimaging projection system; (2.) A center of gravity support; (3.) Object space scanning; and (4.) Lightweight reflecting optics — are sufficiently important to justify improving the reliability of the "C" System (see Section 2).

After careful study, this Corporation's engineering project group is convinced that the necessary reliability of the "C" System can be obtained. A general review of the present optical, mechanical and electrical status (see Section 3) conclusively demonstrates that this reliability can be attained.

Detailed analyses were made of the system to uncover any technical problems whose solution might be prohibitive in time or cost. These problems which are detailed (see Section 4), namely, atmosphere, film, optics, vibration, image motion compensation, and focus, and all have reasonable solutions.

A logical work plan and approach to solve these problems is given (see Section 5). Examination of this work plan discloses no major obstacles and the estimated time to make the "C" System operational is thirty-six weeks.

We have a proposed program (see Section 6) whose acceptance would result not only in an operational "C" System, but also in significant advances in the state of photographic reconnaissance. This is an important program, and we are anxious to undertake it.

2 - OBJECTIVE OF PROPOSED PROGRAM

To the best of our knowledge, the HR-73C Configuration is the only long focal length photographic reconnaissance system, in an advanced development stage, capable of high oblique photography. It is our belief that this is a valuable capability. (See Figure 1.)

Furthermore, the second unique capability of the configuration is that there are four advanced design concepts embodied in this configuration which may be required in future reconnaissance systems. We know of no better way to learn the practical value of these important features other than by the perfection of this configuration. These features are:

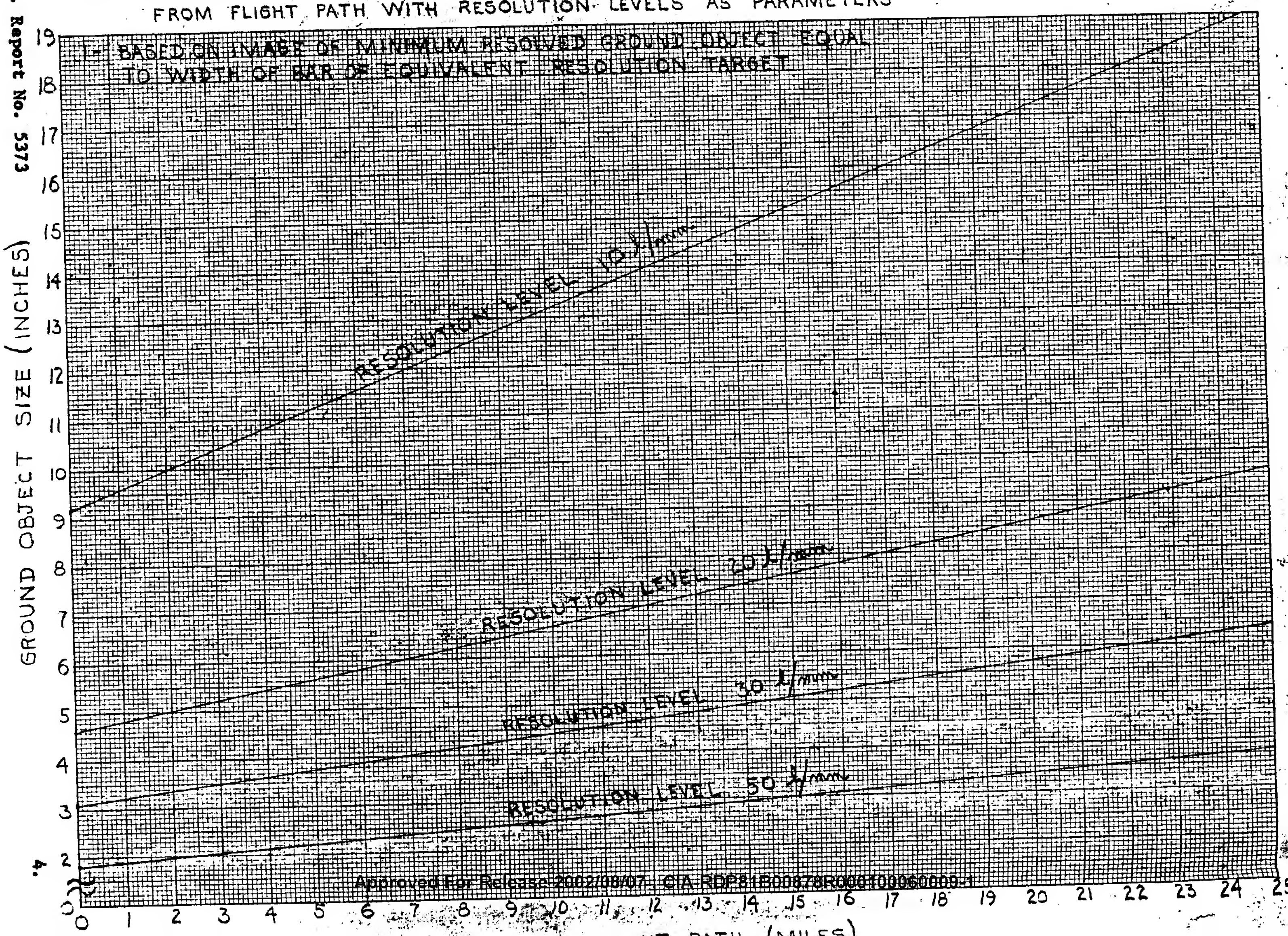
(1) A reimaging projection system. This has two values: It permits the use of fine grain emulsions since the system can be made apochromatic; and it permits a small primary focal plane and a small efficient shutter.

(2) A center of gravity support. This provides inertia stabilization and greatly reduces the weight of stabilization components.

(3) Object space scanning. This feature permits less mechanical clearance for the reconnaissance system, and, alone among the four features, has been successfully proven.

(4) Light weight, high quality reflecting optics. The value of this type of optical element will become more important as the light weight requirement increases, but the feasibility of manufacturing these elements must be determined by testing of overall system performance.

FIG. 1 - SIZE OF MINIMUM RESOLVED ROUND OBJECT AS A FUNCTION OF PERPENDICULAR DISTANCE FROM FLIGHT PATH WITH RESOLUTION LEVELS AS PARAMETERS



In view of these capabilities, the objective of this proposed program is to:

(1) Provide one HR-73C Configuration capable of reliably recording on film the images of ground targets of a quality comparable to the best obtained to date; and

(2) Deliver this configuration, accompanied by an adequately trained operating crew, to a using Detachment within thirty-six (36) weeks.

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3 - PRESENT STATUS

In considering the present status of the configuration, it is especially important to consider both its physical aspects and also the personnel that would be working on the equipment.

The project group that became fully familiar with the configuration during the recent nine month program are convinced, without exception, that the configuration can be made to operate reliably. These people feel that the unsolved problems are not more difficult than those which they have successfully overcome already. This group is still available for assignment to this proposed program and each individual is very interested in carrying this program to a successful conclusion.

The physical aspects of the configuration (serial number 4) are summarized below:

Configuration, Optical

An accurate evaluation of the inherent resolution capabilities of the optical system can be made by examining the photographically recorded static resolution, which was finally improved to about 60 lines per millimeter. Visual observations of collimated resolution targets averaged 60 to 80 lines per millimeter, and a recent auto-collimation of the configuration indicated that a capability of visually resolving 80 to 100 lines per millimeter existed. (A record summary of system resolution is presented in Appendix D, Engineering Report Number 5364, dated 12 January 1959.)

The differences between these static resolution levels and the levels obtained in actual flight can be attributed mainly to such functions as vibrations, uncompensated image motion, and imperfect focus.

As these deteriorating effects are reduced the subsequent in-flight performance level will improve.

Configuration, Mechanical

There are several major mechanical considerations to bear in mind when examining the configuration. Primarily, the mechanical structure itself, and especially the members supporting the optical elements, must not cause or transmit intolerable vibrations. Recent modifications have made significant improvements in this area, and recent tests show vibration levels of the optical elements are within tolerable limits. Secondly, the structure itself was modified to make it more rigid, which is a prerequisite for proper stabilization. Finally, the correct mechanical functioning of each dynamic aspect must be considered. Some minor modifications are indicated: Improvement of the oblique scan bearing; strengthening of the pitch flexure; further testing of the improved shutter; and a critical examination of the film drive assembly.

The mechanical structure of the configuration, in light of present knowledge, is almost satisfactory to perform its intended functions.

Configuration, electronics

The work of the past several months has led conclusively to the realization that the majority of the existing problems are within the realm of the electronics. These problems are somewhat complicated because many modifications have been made and it is necessary to determine just what the existing individual components are and what the existing circuitry is, and only then can the specific cause of malfunction be located and investigated.

The system is plagued with such difficulties as a distorted and varying IMC rate, extraneous signals that produce unwanted flutter in the oblique drive, an inability to maintain the configuration in balance over a long time interval, and tolerances assigned to numerous components which are too broad. Furthermore, the frequency of the existing 400 cycle power supply is not held within necessary limits.

Basic design philosophies, within present knowledge, seem to be sound. The execution must be improved to obtain a satisfactory unit.

Configuration, present capability

None of the flight tests during the recent nine month program were executed without some malfunction (summarized in Appendix C, Engineering Report Number 5364 dated January 12, 1959); the unreliability of the configuration must be eliminated. Individual frames from these flights gave evidence of an in-flight lens-film resolution of 35 lines per millimeter. Spotting accuracy, that is aiming, was good, and the configuration operated in all three modes.

Drawings and Diagrams

With respect to this configuration, many mechanical drawings and circuit diagrams are inaccurate and incomplete.

Manuals

The present set of manuals, to be descriptive of the modified configuration, would have to be extensively revised both to incorporate the many changes and to elaborate on some existing aspects. Within the scope of the proposed program, it is felt that revised manuals may not be necessary for proper maintenance or operation of the configuration, especially if field personnel maintain comprehensive individual notebooks.

Support Equipment:

Two Hand Controls and Memory Units have been used during the recent program. They require a general maintenance and overhaul before they can be recalibrated and considered serviceable again. Except for the inherent disadvantages of the cable linkage from the Hand Control to the Drift Sight, the operation of these units has been satisfactory.

A recent investigation has disclosed that the target image from the 300 inch collimator is being degraded. The cause of this has been attributed to thermal gradients, especially those in the vicinity of the rotating scan mirror. This effect becomes particularly apparent during such seasons when the room containing the equipment cannot be kept at a constant temperature. In addition to this, it is felt that some distortion of the image may be introduced by the scan mirror itself. These two effects should be investigated and minimized in order to have a useful collimator.

Although not essential to proper functioning, certain additional mechanical modifications to the collimator are desirable to improve some presently awkward mechanical adjustments.

The Power Cart has functioned well during use. However, recent configuration test results indicate that the 400 cycle output may be varying and contributing to the observed malfunction of the configuration gyros. The stability of the Power Cart's 400 cycles must be within tolerable limits before it can be considered satisfactory.

The nature, status, quantity and location of equipment manufactured as support or replacement parts for the HR-73C configuration will have to be determined. Much of this equipment is presently located in depots, as back-up and spare parts. A comprehensive listing as well as a control log will have to be established.

4 - TECHNICAL PROBLEMS

GENERAL NATURE OF THE PROBLEMS

There are only six factors which influence final picture taking capability of an aerial camera. In order these are: atmosphere; film; optics; vibration; image motion compensation; and focus.

ATMOSPHERE - Atmosphere has two manifestations. One is the atmosphere external to the vehicle, and the second is the local atmosphere surrounding the camera. The former is something over which an aerial camera has no control, but which is believed to impose no limit in the particular case of the "C" Configuration. The environment within the "C" bag, however, is controllable, and, to the extent that it might impose resolution limitations on the "C" System, it can be dealt with by modifications to that environment.

FILM - The film limitation on resolution is beyond present control. A fast, fine grained, high resolution film is desired. A faster film would be most desirable, since shorter exposures would be permitted, and this would reduce the degradation due to vibration or image motion.

OPTICS - The limitation imposed by optics fall into two areas: Those imposed by the design itself; and those imposed by the execution of the design. In the first case there is no cause for concern with the possible resolution obtainable with the "C" Configuration. In the second case, the light weight mirrors may impose a limit on obtainable resolution.

VIBRATION - Vibration also falls into two categories: Those created by the vehicle; and those created by internal operations of the camera. The

latter have been dealt with extensively, and are now believed to be at tolerable levels, although the shutter vibration level should be retested since the shutter has been modified recently. The external vibration problems can best be reduced by a well executed vibration isolation mount. Such a design is available, and reduction of externally created vibration degradation is possible. Test evidence indicates that only mechanically coupled vibration is a problem, and that acoustically coupled vibration need not be considered.

IMAGE MOTION COMPENSATION - I.M.C. involves the removal of image motion arising from motion of the camera relative to the object. The design of the "C" Configuration is such that drift perpendicular to flight line is not compensated. Furthermore, the errors in sensing, that is, the capability of a driver to set in an accurate track rate, and his ability to determine an accurate track rate from the view presented in the Drift Sight are limitations on the I.M.C. Beyond this problem, there are those problems within the camera which prevent it from adequately compensating such things as distorted signals in the stabilization, positioning or auto-balance circuits, and flexure of the entire piece of hardware under the influence of stabilization, for instance.

FOCUS - Focus requires the image to be in coincidence with the emulsion during exposure.

Evidence indicates that focus achieved to date is adequate. However, there is no doubt that a lessening of degradation due to I.M.C. and vibration will more critically test focus, but the laws of nature will not prevent focus being improved. In fact, there are only hardware type problems involved in improving focus if this is required by better resolution levels.

SPECIFIC DETAILS OF THE PROBLEMS

The specific problems of the "C" Configuration fall generally into the last three areas, that is, image motion compensation, vibration, and focus in order of problem magnitude. There is also the very critical problem of reliability, since the configuration must actually operate before deficient operation can be lessened. Finally, there must be some special instrumentation. The technical details of salient problems are discussed below:

IMAGE MOTION COMPENSATION - There are several problems in the area of image motion compensation:

Pitch I.M.C. - The yaw and roll stabilizers are closed loop systems. In such systems variation in internal gain has only second order effects. The I.M.C. is introduced into the pitch stabilizer by means of an open loop system; consequently, any variation of parameters has first order effects on the I.M.C. rate.

This problem can be overcome by closing the loop, or improving the open loop stability. The most attractive solution is to improve the open loop stability by applying the advances in transistors and transistor circuit design which have occurred since the original design; this has the further advantage of permitting weight reduction.

Auto-balance - Tests on the existing system failed to either prove or disprove the adequacy of the auto-balance. There is reason to suspect, however, that the performance is marginal. Critical testing will be needed to establish the exact status of the auto-balance.

Stabilizers - There is reason to believe that the existing gyro stabilization loop is either adequate or very close to being adequate.

This cannot be determined unless some very accurate and careful tests are performed.

However, the equations for stabilization contain a first order term proportional to the angular momentum of the gyro spin wheel. The angular velocity of the spin wheel is of course proportional to the supply frequency (nominally 400 cycles). Considering the high accuracy required, variations in supply frequency can be expected to produce relatively large variations in stabilization accuracy.

The 400 cycle supply requirement can be met best by a transistorized inverter rather than an engine driven alternator. The frequency and voltage of the inverter can be controlled within close limits. An inverter similar to that in the Hand Control could be used and would allow overall weight reduction.

The limited test time with the positioning servo has not permitted any accurate conclusions on this device.

Flexures - The stabilization solenoid flexure links presently installed between the stabilizing solenoids and the camera body have repeatedly failed due to fatigue cracking. This prevents stabilization and can result also in damage to the configuration; ball and socket joints are one possible solution.

External Command Equipment - An equipment group consisting of the Drift Sight, Hand Control, Memory Unit and the Operator serve to supply the Configuration with information which directly commands the I.M.C. rate and controls positioning and aiming. Any distortion of information produced by this command group will be translated into errors in the operation of the configuration.

There has been considerable speculation as to whether the visual information that the operator receives is enough to enable him to make accurate and correct adjustment, and also whether the operator skill has been developed to such an extent that he is able to make maximum use of the information he receives. In addition to this, the inherent tendency of the flexible cables, which link the Hand Control to the Drift Sight, to bind, causes irregular movement of the visual presentation. This can lead to errors in the ultimate aiming accuracy and in I.M.C. error.

Whether the magnitude of any of these effects is enough to cause concern has not yet been determined, but shall have to be investigated. Employing the Askania space positioning facility which could be made available for this purpose, an accurate speed and altitude determination of the vehicle could be made. Coordination of this information with airborne instrumentation and photographic results would produce data from which the magnitude of this problem could be assessed.

Upon this basis, modifications which would improve configuration performance would be investigated. Operator training may have to be increased. In the event of a flexible cable binding problem, the possibility of adapting a MK II Hand Control so that it could be used with a Memory Unit would be considered. The MK II unit eliminates the use of cable linkages and uses an electrically coupled servo system instead.

<u>VIBRATION</u> - The present limitation on resolution is due to uncompensated image motion. When this degradation is reduced the next limit will almost surely be externally created vibration.

The best solution to this problem is the use of well designed isolators. These are available from Robinson Aviation, Incorporated, and will be procurred for installation.

FOCUS - The photographic results of July and August 1958 were carefully scrutinized and no indication of focus shift was found. Malfunction occurred later due to a mistake in the wiring, leading to some confusion. However, the temperature control has been returned to the original version and is expected to function satisfactorily, based on the previous resolution level. The existing temperature control system is an on-off type. When the configuration is improved sufficiently so that temperature shift of focus becomes important, a substitute temperature control system is available. This system is a magnetic amplifier servo of the proportional plus integral type, and should be able to control temperature to a small fraction of a degree. The proportional system will be tested on a separate lens barrel, and, when the actual performance becomes superior to the present control system, the new system will be installed in the configuration; this will provide a margin of safety.

RELIABILITY - Reliability is of prime importance in attaining the objectives set forth for this program. Not only must the level of reliability be determined, but it must be sufficiently high to insure the configuration's usefulness to the program. Recent flight tests have demonstrated that this is an area which requires high priority.

The average expected useful lifetimes of components will have to be determined in all cases where such information is not already available. Component substitution for reason of insufficient reliability or life span will be incorporated on the basis of this information, until a satisfactory level of performance for the Configuration can be maintained. In addition to this, a comprehensive control log of component running times will be established, so that expended units can be replaced prior to failure.

Some specific problems of unreliability are:

Film Transport - The film transport is not reliable at present. It mismeters frequently in Mode I operation and has suffered from frequent film wraps. Both malfunctions can be traced to faulty friction devices between the film drums. This variable friction causes overloading and slipping of the metering roller and also overloading and near stalling of the take-up motors.

It is therefore necessary to:

(1.) Replace and modify the friction material on the film spools with more suitable material, such as nylon and metal bearings.

(2.) Establish optimum frictional loading of film spools for proper functioning and also a simple means for field checking this.

(3.) Re-examine take-up motors with respect for torque requirements as indicated by results from item 2.

Vacuum Solenoid - The vacuum solenoid in its present state is a major cause of vibration affecting the whole configuration and particularly the scanning flat as shown on test records. This is caused by the too rapid deceleration (impact) of the solenoid slug on opening and closing, and also incorrect mounting of the shock absorbers, which now are placed at right angle to the direction of shock.

It is therefore necessary that;

(1.) The vacuum solenoid be modified to reduce the deceleration of the slug by replacing the rigid valve disc with a flexible one.

(2.) The mounting of the shock absorbers be changed so that they function correctly, if they are still required after modifying the solenoid.

Oblique Drive Vibration - It has recently been observed that the scanning flat vibrates or oscillates between each exposure. It is not clear at this time whether this is caused by electrical "noise" or is strictly of a mechanical nature.

If this performance defect is electrical it can be eliminated by ascertaining whether the disturbance is induced internally or externally. If the disturbance is from the exterior, shielding and/or filtering will eliminate it. If the problem is interior, that is loop instability, changes in the loop transfer function will solve the problem.

If this performance defect is mechanical, that is, friction or stiction, replacement or lubrication of the offending components will dispose of the problem.

Programmer - The existing programmer consists of 2 11-point rotary switches. The reliability and life has been poor.

A manufacturer was contacted who makes use of these switches in traffic controllers. Life and reliability in these controllers has been good, but the cycling rate is much slower than in the "C" Configuration; and the standard practice of this manufacturer is to adjust these switches to tolerances far smaller than those specified by the switch manufacturer. The traffic control manufacturer prefers another switch to the one used in the "C" programmer and is discontinuing the use of the present switch. However, this superior switch is both larger and heavier.

This problem can be solved by (a.) very careful adjustment and maintenance of the existing switch, (b.) by replacing the switch with the superior switch, or (c.) by using a diode-relay sequencing system similar to that used in the intervalometer on the MK II, Model 501 Tracking Camera.

Solution (c.) is the best of these possibilities. No critical adjustment is necessary, and there is a good possibility of weight reduction.

TEST EQUIPMENT - In the course of the recent field activities, a number of shortcomings of the available test equipment have become apparent; these can be divided into necessities and time savers. All shortcomings will be corrected.

The necessities are:

(1.) An attachment for the 300" collimator to simulate effect of ground speed to test IMC performance. The existing improvised attachment needs to be refined.

(2.) An optical system to observe the performance of the scanning flat drive and stabilization during ground test runs. This is 90% completed.

(3.) Two 6" test mirrors required for a systematic check-out of the optical components or sub-assemblies of the optical system. These are completed except for aluminizing.

(4.) A structural modification of the test stand permitting the use of the 300" collimator in the oblique mode of operation.

(5.) Modification of an existing auto-collimating microscope for better performance.

(6.) A 400 cycle supply from the ground power cart which has an actual frequency output identical to the vehicle's 400 cycle. Standard techniques will allow this.

The time savers are:

(1.) A modification of the manual control of the 300" collimator flat so that it can be swung rapidly from the vertical, that is, the auto-collimating position to the 45° or operating position. This can be accomplished by a simple peg and hole arrangement.

(2.) The present arrangement used to square-on the film platen is cumbersome and time consuming. This can be greatly improved by the addition of another microscope, and by mounting these on two rails for rapidly scanning the four corners of the platen.

Finally, the performance of the 300" collimator has not always been satisfactory. Last summer's tests have shown repeatedly that stratification of the air and thermal air currents are major contributors to the observed image degradation. This does not, however, exclude distortion of some of the optical elements due to thermal effects or other causes. The observed behavior is not fully understood and some time should be allocated to determine its true nature.

5 - WORK PLAN AND SCHEDULE

The proposed program to accomplish the outlined objectives has nine phases (see figure 2):

Phase I - Set up (2 Weeks)

The objective of this phase will be to set up the required equipment in the contractor's existing "C" room in such a manner than an orderly study program can be implemented. To accomplish this, the "C" Configuration (Serial No. 4) and certain associated equipment must be transported from the Farm to the contractor's plant. This equipment will then be set up to permit a successful study.

Phase II - Study (3 Weeks)

The objective of this phase will be to learn the exact details of the present circuitry. The known presence of obsolete wiring and components, and the inaccuracies in the present schematic wiring diagrams necessitate a thorough initial study of the "C" Configuration. Obsolete parts will be removed, and the drawings will be corrected, as a result of a systematic item-by-item study of the electro-mechanical components.

Phase III - Test Components (6 Weeks)

The objective of this phase will be to achieve adequate performance from each individual functional component. Presently, there are no concepts which are incorrect; there are merely faults of execution. However, if any conceptual falacies are uncovered in Phase II these will be dealt with prior to component testing. It is more likely, however, that the deficient components can immediately be tested and modified.

Phase IV - Ground System Tests - (6 Weeks)

The objective of this phase will be to learn which inter-relationships of functional components cause the system to perform at a capability less than the

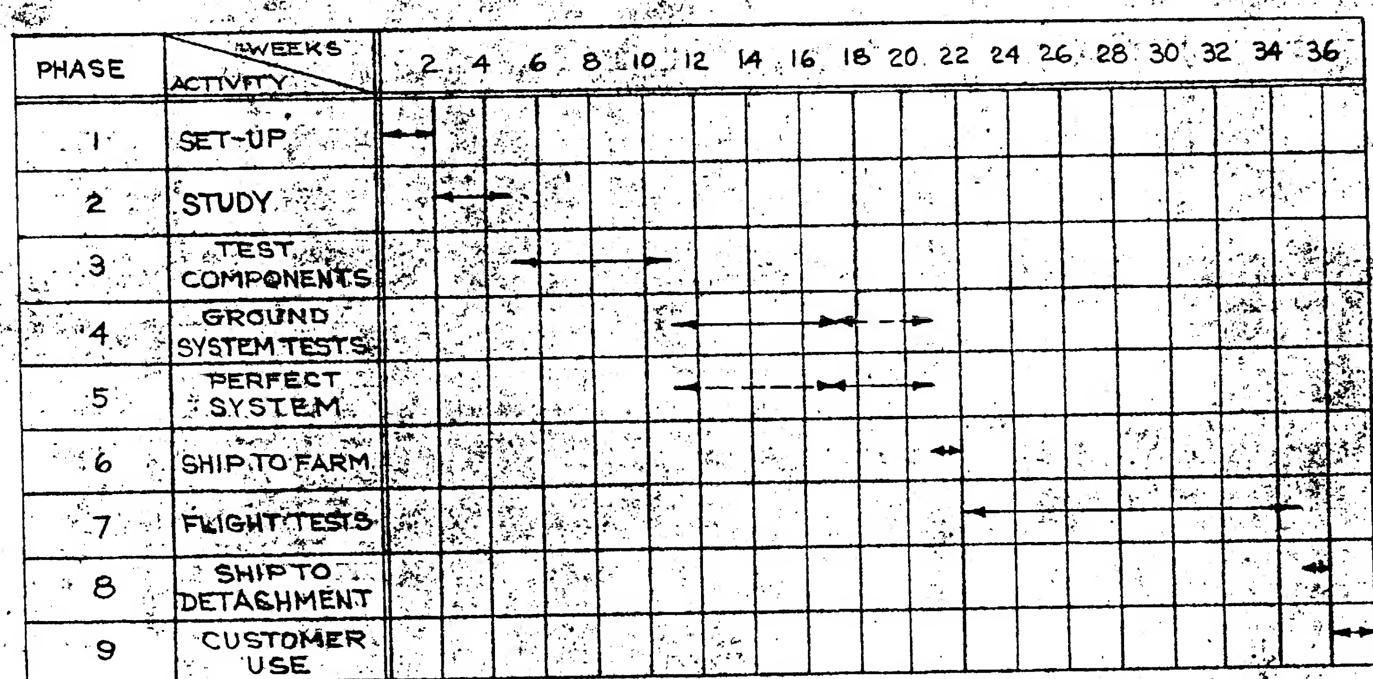

FIGURE 2: PROPOSED SCHEDULE

capability which individual component capabilities should permit. The entire system (Hand Control and Configuration) will be subjected to tests which approximate to the greatest practical extent the conditions of normal use. At least two complete successive runs are considered as a minimum indication of system reliability. The instrumentation required for these ground system tests will be fairly elaborate. However, during phases I, II, and III, as a parallel effort to those phases, the required instrumentation can be developed and tested so that no delay to the entire program will result.

<u>Phase V - Perfect System</u> (4 Weeks)

The objective of this phase shall be to bring the system performance to that level permitted by the individual component performance levels; that is, to the design level. In actual fact, Phase V will probably blend in with Phase IV, since such system interrelation defects as are exposed in Phase IV will be corrected by Phase V activity, but the final conclusion of both phases will be the two complete successive runs. The reason and necessity for considering Phase V as separate from Phase IV is that Phase V may never be required if Phases III and IV result in satisfactory performance.

<u>Phase VI - Ship To Farm</u> (1 Week)

The objective of this phase will be to move the "C" Configuration and the associated equipment to the Flight Test Site. The "C" Configuration will be packed and transported to the Farm, and unpacked in a room suitably arranged to permit successful flight test operations.

<u>Phase VII - Flight Test</u> (13 Weeks)

The objective of this phase will be to prove that the "C" Configuration can achieve suitable performance in the actual environment of use. The initial effort of this phase will be directed to finding and holding air focus. Experience indicates that three to five flights will be required for this purpose. The next phase will be to determine that the "C" Configuration in

the vehicle is both reliable and capable of taking photographs of an adequate quality. Three to five flights should be adequate for this purpose.

Maximum value in a flight test plan requires that there be approximately six to eight work days between flights, so that data may be fully analyzed. Consequently, considerable time is allowed for this phase.

<u>Phase VIII - Ship To Detachment</u> (1 Week)

The objective of this phase will be to move the equipment and such personnel as are required for its operation to a using detachment. The required equipment accompanied by trained operating personnel will be transported from the test site to the using area.

<u>Phase IX - Customer Use</u>

The objective of this phase will be to provide the customer with an operable "C" Configuration and the personnel to operate it. With one "C" Configuration at a Detachment, it is believed that four people will be required to successfully operate it according to the customer's requirements.

6 - PROPOSED PROGRAM

The Corporation believes that this program is sufficiently important so that any personnel required by the project group will be made available by the Corporation. The estimated requirements (see figure 3) are such that security clearance should be made confidential with respect to the hardware. (Knowledge of customer and use will continue to require project clearance.) The nucleus of the proposed project group (see figure 4) includes personnel fully familiar with the existing configuration as well as other reconnaissance system experts from within the Corporation. Also, the project group will have available any facilities, in addition to the existing C-room, that are required.

With this Corporation support, the program we propose is that: The project group will carry out the work plan according to the proposed schedule so as to solve the technical problems and accomplish the program objectives.